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ABSTRACT

Sperry (1961) and others working on split brain learning reported that the two halves function in a nearly identical manner, giving excellent controlled replication of a learning problem. The present experiments were carried out with cats trained in a tactile discrimination apparatus, sometimes being forced to use the left paw, and sometimes being forced to use the right paw. The data were analyzed in terms of parameters of the Audley-Jonckheere (1956) learning model and also in terms of the conventional measures of total trials, total correct responses and total errors to criterion. Varying results have been reported in the literature. Possibly there are some conditions under which first and second brain learning results agree (replications), others under which they are related randomly and still others under which there is transfer from one half brain to the other. If limited conditions can be clearly defined under which replication will occur, then an investigation of learning curve theories through replication by brain experiments would be possible. (Author/CK)

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AN ATTEMPT TO OBTAIN REPLICATE LEARNING CURVES

Harold Gulliksen
Princeton University
and
Educational Testing Service

and

Theodore Voneida
Case Western Reserve University

Prepared in connection with research sponsored
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Principal Investigator: HAROLD GULLIKSEN

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Principal Investigator: NORMAN FREDERIKSEN

United States Public Health Service
Grant No. MH-07051 to Case Western Reserve University
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13. ABSTRACT

Sperry (1961) and others working on split brain learning reported that the two halves function in a nearly identical manner, giving excellent controlled replication of a learning problem. Sperry states "these controls are not only of the homozygous identical-twin type, but are equated also for almost all experientially derived organization implanted up to the time of splitting. These contralateral cerebral controls are thus of a quality almost impossible to obtain by using different animals." Such a situation would furnish an excellent opportunity for investigating learning curves and parameters of learning curves to differentiate random error from a systematic discrepancy between learning data and learning theory.

The present experiments were carried out with cats trained in a tactile discrimination apparatus, sometimes being forced to use the left paw, and sometimes being forced to use the right paw. Two groups of animals were used, one trained at Princeton University, the other at Case Western Reserve University. Various tactile discriminations were required, one pedal being reinforced by food and the other sounded a buzzer. All operative procedures (midline section of forebrain commissures), as well as postmortem histological examination of the brains were carried out in Dr. Voneida's laboratory.

The data were analyzed in terms of parameters of the Audley-Jonckheere (1956) learning model and also in terms of the conventional measures of total trials, total correct responses and total errors to criterion. The data gave no clear evidence

(See continuation page)

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lateralization						
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discrimination						

13. Abstract (Continuation page)

that second brain learning replicated first brain learning. The relationship was sometimes positive, occasionally negative and usually zero. High correlations and also an index reflecting the degree of equality of two sets of measures were found for the conventional measures for the PR group on the ba problem, this problem presented to the animals after five previous sets of problems had been experienced.

Varying results have been reported in the literature. Best (1965) reported data from Meikle (1960, 1964) and from Meikle and Sechzer (1960) which show high agreement between first and second brain learning in a brightness discrimination, as well as in a pattern discrimination, in split brain cats. Russell, Plotkin, and Kleinman (1970), on the other hand, found that there was a good correlation between mean performance for first and second brain learning on problems of five different levels. However, when one looked at the individual results the correlation of first with second brain performance was essentially zero for each of the difficulty levels.

The parameters of the Audley-Jonckheere learning model were studied in the present investigation, and the major ones appearing in the data were Rho_0, the initial probability of a correct response, and Alpha, the influence of reward of a correct response in increasing the strength of the correct response. Both parameters are based on a maximum likelihood estimate using the entire record.

Meikle, Sechzer, and Stellar (1962) reported that cats with pretraining section of the corpus callosum showed no transfer of a flexion response to skin stimulation (UCS was electrical shock), and required complete retraining of this response with the opposite brain half. Right- and left-brain learning measures appeared close to equality for flexion responses, but not for respiratory responses.

The concept of hemispheric equality has been questioned, however, by Robinson and Voneida (1973) and by Webster (1972), whose studies have demonstrated both quantitative and qualitative differences between the cat's hemispheres.

Possibly there are some conditions under which first and second brain learning results agree (replications), others under which they are related randomly and still others under which there is transfer from one half brain to the other (failure of lateralization, or failure of replication). If limited conditions can be clearly defined under which replication will occur, then an investigation of learning curve theories through replication by split brain experiments would be possible.

An Attempt to Obtain Replicate Learning Curves[1]

Harold Gulliksen

Princeton University and Educational Testing Service

Princeton, New Jersey 08540

and

Theodore Voneida

Case Western Reserve University, School of Medicine

Cleveland, Ohio 44106

This study of learning curves in normal and split brain cats investigated different methods of analyzing learning performance and determining individual characteristics of learners. One of the severe handicaps of studies of learning has been the impossibility of replication. If a subject has learned a task and a learning curve has been recorded, then it has been impossible to repeat the experiment. If the same learning task is used, the subject already knows it; if a different task is used then, due to positive or negative transfer, a learning curve different from the first one is expected; if a different subject is used, then his learning ability for this task may differ. In all three cases one has no replication of a given learning curve. This means that it has never been possible in the hundred years of psychological study of learning to differentiate random error in the fit of learning theory from systematic deviations due to inadequacy of the learning theory.

Research by Sperry (1961) and others used the technique of sectioning the corpus callosum to divide the brain into two autonomously functioning halves. These workers have presented some evidence to indicate that the two halves of the brain not only function autonomously, but also function in a nearly identical manner. A few records have been published in which the

right-brain learning curve appears to be essentially a replicate of the left-brain curve. If conditions can be defined under which this holds, then we have for the first time the possibility of replicating a learning experiment, which amounts to the possibility of experimenting with identical twins raised in identical environments. Sperry (1961) states, "With the brain bisected, it becomes possible to direct one's ablations, tests, and other analytic procedures to a single one of the hemispheres, leaving the 'spare' hemisphere for the use of the animal. In addition to the obvious benefit to the animal over the usual bilateral invasion, there are a number of significant technical advantages in working on the half brain instead of the whole brain. It is important to remember in this connection that the half brain is, in a sense, pretty much a whole brain in that it contains a complete set of cerebral integrating centers, and all their interrelations. That is, practically the entire pattern and most of the problems of cerebral organization are there for the unraveling within the half brain." Such a situation would furnish an excellent opportunity for investigating learning curves and parameters of learning curves to differentiate random error from a systematic discrepancy between learning data and learning theory.

The value of the split brain preparation as a tool for investigating learning curve parameters, however, depends heavily on the concept of hemispheric identity. This concept has been questioned recently by Robinson and Voneida (1973) whose studies strongly suggest that split brain cats have a greater cognitive capacity in one brain half than the other. In addition, Webster's (1972) study of qualitative differences between the hemispheres led him to conclude that the separate hemispheres are specialized for processing different kinds of information.

The present study utilizes the tactile modality in split brain cats to further analyze the degree to which the two brain halves function as similar or dissimilar units.

Procedures

In the present experiment, the methods and apparatus used by Stamm and Sperry (1957) and Sperry (1961) were followed with some modifications. The cat was placed in an experimental box with vision restricted, such tha he could not see the two pedals to which tactile stimuli were fastened, but could reach out to touch and depress either one. The paw not used in an experiment was hobbled in a leather strap so that only one paw could be used to touch the pedals. Depression of the "correct" stimulus pedal automatically delivered a food pellet, while depression of the "incorrect" pedal caused a buzzer to sound. Two groups of cats were used in the investigation to test the learning of tactile stimuli, one group at Princeton University in the Psychology Department animal laboratory (group PR) and one group under the supervision of Dr. Theodore Voneida at the Department of Anatomy, Case Western Reserve University (group WR). The two groups of animals were trained under the above conditions. There were additional features for the PR group. The pedals were wired to a keypunch so that right or wrong responses were recorded, along with identifying codes, on IBM cards. Also, two additional problems, which proved to be very difficult, were given to the PR group, and the animals in these cases refused to work. A change was then made in the food reward. Instead of dry cat food pellets, small pieces of cooked liver were dropped from the automatic feeder when the "correct" pedal was pressed. This change in food brought a marked

change in motivation, such that the cats consistently pressed the pedals; whether or not they learned the problem.

Three pairs of tactile stimuli, as shown in Table 1, were presented to nine cats in the WR group. This group consisted of two normal subjects (Sy and Am), four with section of the corpus callosum and anterior commissure (Pa, Ba, Ar, Ho), and three with section of corpus callosum only (Ch, To, Ca). Midline surgery was performed by Dr. Voneida, either before or after the first pair of problems, as indicated in Table 9. Both left and right paws were trained on each pair of stimuli.

Insert Table 1 about here

The PR group of five cats consisted of six-month-old, naive animals. They began the series of experiments in the normal condition and were trained on three pairs of stimuli, first with one paw, then with the other paw. For each pair of stimuli, two cats had a given stimulus positive, while the other three cats had the other stimulus positive. Four animals then had the corpus callosum and anterior commissure sectioned after the fifth or sixth problem, as indicated in Table 10. A fifth cat was normal throughout the experiment. After the first six problems, the PR cats were trained on three new pairs of stimuli, each with left and right paw, the positive stimuli differing for two of the four operated animals. The stimuli and problems used for the PR cats are shown in Table 2. The stimulus which was positive for problems 11 and 12 was reversed for problems 13 and 14.

Subsequent to all training procedures, the brains were perfused in Dr. Voneida's laboratory, and after a suitable period of fixation were

sectioned and stained according to the Weil technique. The completeness of midline section was verified in each operated subject by microscopic examination.

Insert Table 2 about here

Shaping Procedure

Successive steps were taken to accustom the animal to the experimental box and to reaching out of the box for the pedals and pressing them. The animal was first fed in the box. The process of reaching out of the opening in the front of the box to the pedals was accomplished by first using a metal extension to one pedal which brought food into the experimental box. The pedal was moved farther from the box opening until it was at the distance from the cat used in the learning experiments. When the pedal was pressed, it would bring a food drop from the automatic feeder. Next, two pedals were presented to the animal, simultaneously. Either one, if pressed, resulted in a food drop. The two tactile stimuli which were to be discriminated were then fastened on to the two pedals, and a food drop occurred only when the "correct" pedal was pressed.

Training Procedure

It was usual for the animals to show a strong position habit at first, which was usually followed by a lesser position habit on the opposite side. To eliminate this, and to keep the animal working on the problem, it was found that holding the incorrect pedal in place after a series of incorrect responses led the animal to try the alternate or correct pedal.

At first the animal was allowed to make ten incorrect responses before he was led to correct himself. Later a run of five incorrect responses was permitted before the incorrect pedal was held, leading to a correct response when corrected. If the animal did not achieve success, either by trying an alternate pedal of his own accord, or by the experimenter inducing the change by holding the pedal, the cat often refused to work.

The WR animals were regularly given 50 trials per day. The criterion of learning was 90% or more correct responses on three consecutive days. If this level was not reached, the experiment was terminated after the animal had reached a plateau, or had fallen consistently below its highest level of performance. The PR group was given 50 trials per day or 30 correct responses, whichever came first. The criterion of learning was 90% correct responses on three consecutive days. For both the WR and PR groups a random order of stimuli was used. If the animal learned to change and press the alternate pedal whenever an error was made, it was possible to get 66% correct responses in a day. It was considered that the animal could not learn to discriminate members of a pair of stimuli unless one of the two paws learned the problem to 80% correct for three consecutive days. The pair of stimuli hg were different for the PR and WR groups. For the WR group hg was a set of horizontal ridges vs. vertical ridges made of metal with spaces between. In an attempt to get a slightly more difficult problem than ba (brush-flat) the PR group was given hg as horizontal vs. vertical flat bars with spaces between. The PR group was also given the problem ab, the flat wooden block positive, and could not learn this later in learning (problems 11-14), but could learn it in either problem 1 or 3.

Methods of Analysis

The usual measures of learning have been in terms of trials to criterion or number of errors or correct responses to criterion. These measures were employed in the present experiment. In addition to these conventional measures, the present investigation has taken a theoretical formulation of learning, the Audley-Jonckheere (1956) learning model of which Gulliksen (1934, 1953) is a special case, and determines the values of the parameters of this model from the data on the split brain cat learning records. James Ramsay of McGill University has written a computer program for estimating parameters in the Audley-Jonckheere learning model and for carrying out the analysis of the learning data.

In applying the learning model proposed by Audley and Jonckheere (1956) to a learning problem in which there are only two possible responses, correct and incorrect, the probability of a correct response on any trial is the ratio of the habit strength for that response on any trial to the sum of the habit strengths for the two possible responses. The sequence of learning trials commences with some initial probability of a correct response Rho_0 . The response on any given trial affects the probability of a correct response through the increase or decrease of the habit strength of the correct and/or incorrect response. The following relationships may be defined:

Rho_0 = the initial probability of a correct response

Alpha = an amount by which a correct response increments the correct habit strength (α)

Gamma 1 - Alpha = an amount by which a correct response increments the incorrect habit strength ($\gamma_1-\alpha$)

Beta = an amount by which an incorrect response increments the correct habit strength (β)

Gamma 2 - Beta = an amount by which an incorrect response increments the incorrect habit strength ($\gamma_2 - \beta$). See Table 3.

Insert Table 3 about here

Let X_i indicate the response on trial number i, taking the value of 1 if the response is correct and 0 if it is incorrect. Let $K_n = \sum_{i=1}^{n} X_i$ be the number of correct responses before trial i. Then the probability of a correct response on trial $n + 1$ according to the Audley-Jonckheere (1956) model (see equation 2 on page 89 in reference) is

$$(1) \qquad P_r\{X_{n+1} = 1 | K_n\} = \{\rho + (\alpha - \beta)K_n + n\beta\}/\{1 + (\gamma_1 - \gamma_2)K_n + n\gamma_2\} \quad .$$

This model can be distinguished in important practical ways from certain Markov and linear operator models (which are special cases of habit strength models). This model readily accommodates very slow learning such as one finds in some types of animal studies. The distinguishing feature is the effect of a correct response on learning late in the sequence. The habit strengths become progressively larger and the relative effects of the constant increments become progressively smaller. Finally, this model depends only on the number of correct responses prior to a given trial and not on the probability of a correct response on the previous trial.

Parameter Estimation

A least squares procedure is used for the initial approximation of the parameters for the maximum likelihood solution. The normalized gradient method is then used, beginning with every n-th trial in order to speed computing at first. When an appropriate accuracy level is reached the program changes to utilizing every trial. There is also a procedure for increasing or decreasing step size. When the gradient length is near zero, the program changes to a successive approximations procedure, utilizing second as well as first derivatives. In the final set of iterations the program computes and prints all the first and second derivatives, as well as eigenvalues for the matrix of second derivatives. Convergence to the maximum solution is definitely tested by near zero first derivatives and by negative eigenvalues for the matrix of second derivatives. Convergence indicates that the program was successful in identifying the values of the parameters where the likelihood function was at a maximum.

Results

The results of the analysis in terms of parameters of the Audley-Jonckheere model are shown in Tables 4 to 7. Table 4 gives the results on normal animals,

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Insert Table 4 about here

Sy and Am for the WR group. These animals were trained on problems ba, dc, and hg. The initial probability of a correct response (Rho_0) ranged from .3996 to .6215. Trials including three criterion days for those who learned ranged from 658 to 3259. For most of the problems learning was due to the

reward of a correct response increasing the strength of the correct response (α). Note that one animal, Am, took more trials for the second paw learning (1803) than for the first (858).

Table 5 gives the parameters obtained on operated animals of the WR group: Ch, Pa, Ar, To, and Ca, trained on problems ba, dc, and hg. The initial probability of a correct response (Rho_0) ranged from .3126 to .5995. Trials including three criterion days ranged from 485 to 2680. Again for most of the problems learning was due to the reward of a correct response increasing the strength of the correct response (α). The comparison of Rho_0 and Alpha (α) for first and second paw will be presented when Figure 1 and Figure 2 are discussed.

Insert Table 5 about here

Table 6 gives parameter results on normal cats of the PR group trained on problems 1, 3, 4, and 5 with stimuli ba, ab, and ef. The initial probability of a correct response ranged from .2431 to .7084. Again for most of the problems learning was due to the reward of a correct response increasing the strength of the correct response (α), although in seven cases Beta (β) was an important influence, and Gamma 1 - Alpha ($\gamma_1 - \alpha$) in three cases.

Insert Table 6 about here

Table 7 gives the parameter values for animals Ev, Cl, Ld, and Fi after operation (Ru remained normal) in the PR group. Six of the records (marked with a b) did not reach 80% correct and are regarded as not having learned

the problem. For the other records, Rho_0 ranged from .1612 to .5996. For most of the problems, learning was due to the reward of a correct response increasing the strength of the correct response, (α), but in two cases of those that learned, Beta (β) was effective, and in one case, Gamma 2 - Beta ($\gamma_2 - \beta$).

Insert Table 7 about here

The comparison of first and second paw learning parameters for both the WR and PR groups for Rho_0 is shown in Figure 1. The agreement is not very high. Similarly, the comparison of first and second paws for the values of Alpha for both the WR and PR groups is shown in Figure 2. Again the agreement is not very high.

Insert Figures 1 and 2 about here

Three indices of agreement between right and left paw results were computed.

(2) $$r = \Sigma xy/(\Sigma x^2 \Sigma y^2)^{\frac{1}{2}}$$

(3) $$R_1 = 2\Sigma xy/(\Sigma x^2 + \Sigma y^2)$$

(4) $$R_2 = (2\Sigma xy - W)/(\Sigma x^2 + \Sigma y^2 + W)$$

where $W = (1/2N)(\Sigma X - \Sigma Y)^2$,

X and Y represent gross scores, and

x and y represent deviations from the mean.

$\underline{r}$ is the usual Pearson correlation coefficient. It equals unity if $Y = aX + b$ or if $y = ax$, it equals zero if $\Sigma xy = 0$, and it equals -1.0 if $y = -ax$.

$\underline{R}_1$ depends only on deviation scores. It is unity if $X_i - \overline{X} = Y_i - \overline{Y}$ or $x_i = y_i$ for all i, and equals zero if $\Sigma xy = 0$, and equals -1.0 if $x_i = -y_i$ for all i.

$\underline{R}_2$ is an index which equals 1.0 if $X_i = Y_i$ for all i; and equals zero if $\Sigma(x + y)^2$ equals $\Sigma(X - Y)^2$; and equals -1.0 if $X_i = -Y_i$ for all i.

Values of r, R_1, and R_2 for Rho_0 and Alpha are shown in Table 8. For the other parameters so few of the values were nonzero that values of r, R_1, and R_2 could not be computed.

Insert Table 8 about here

Since it is theorized that learning measures in the split brain animals would be equal for left and right paw performance on the same tactile problem, the values of R_2 should be large if the measures were equal. Where R_2 is small, even though $\underline{r}$ is large, it indicates that though the correlation may be high, the values of X and Y are far from equal. R_1 expresses the relationships between deviations from the mean.

In general these results do not agree with the view that second paw learning in split brain animals is a replication of first paw learning of tactile problems. Considering the possibility that the conventional measures of trials, errors, or correct responses to criterion might show replication

when learning curve parameters did not, the data were analyzed in terms of these conventional measures. Total trials to criterion for normal and operated animals for the WR groups are shown in Table 9.

Insert Table 9 about here

The savings score is given as a percentage:

$$\frac{\text{trials on \#1 paw} - \text{trials on \#2 paw}}{\text{trials on \#1 paw}} \times 100 \ .$$

Where there are more trials with the second paw than with the first, a negative savings score occurs. Where there are fewer trials with the second paw than with the first, a positive savings score occurs. Where there is transfer from the first set of trials to the second, as is expected to occur in normal animals, there are fewer trials with the second paw, giving a large positive percentage where there is a high degree of transfer.

In the cases shown in Table 9 the normal animals showed savings scores ranging from +33% to +55% on problem ba. The split brain animals with the corpus callosum sectioned showed equally large positive savings scores, which was not expected with the view that the two halves of the brain were acting somewhat independently and in a like manner. On the dc and hg problems the normal animals showed savings scores both positive and negative. For the split brain animals savings scores ranged from +85% to -74%, the great majority being positive scores.

Insert Figure 3 about here

Total trials to criterion for normal and operated animals for the CR group are shown in Table 10. On problems dc and cd the normal animals, and

those with cc-ac after the first paw learning, showed savings scores of 83% to 96% positive, indicating a high degree of transfer on these problems as expected with normal animals. There was also a high degree of transfer on the fe, ef problems except for one case. On subsequent problems with the animals operated for cc-ac, the problems hg, gh, df, fd, and ab were too difficult for most of the animals. On the ba problems (11-14), where a high degree of learning took place, savings scores were negative -2% to -20% for the operated animals.

Insert Table 10 about here

Total number of correct responses to criterion for normal and operated cats for the WR group are shown in Table 11. Savings scores on the ba problem were all positive for the normal animals, while for the operated animals there were positive and negative scores. One normal animal, Am, showed variations on savings scores from 95% positive for problem hg to 182% negative for dc. The great majority of operated animals showed positive savings scores on all three pairs of problems ranging from 86% to 4% positive.

Insert Table 11 about here

Total number of correct responses to criterion for normal and operated cats for the PR group is shown in Table 12. Again for the dc, cd problems the normals, and normals operated after first paw learning, had total correct responses showing large positive savings scores, indicating a high degree of transfer, as would be expected. Likewise for the five normal cats on the fe, ef problems there were large positive savings scores except for one cat with a large negative savings score.

Insert Table 12 about here

The comparison of total correct responses to criterion for first vs. second paw learning for operated animals that reached the criterion is shown in Figure 4. As with total trials to criterion (Figure 3), about half the split brain cats showed much larger scores for the first paw learning than for second paw learning, the other cats showing pairs of responses much closer to the line where $X = Y$.

Insert Figure 4 about here

Total errors to criterion for the normal and cc-ac operated cats for the WR group are shown in Table 13. Large positive and negative scores were found for both normal and operated animals. The positive scores predominated.

Insert Table 13 about here

Total errors to criterion for the normal and operated cats for the PR group are shown in Table 14. Large positive scores for normals on dc, cd, and fe, ef problems occurred. These problems were all learned to criterion. Such positive transfer was to be expected for the normal animals and those who did the first problem in the normal state and then had the cc-ac operation before doing the second paw problem. For the ba problem there was less deviation from zero for the operated PR cats than for the operated WR cats on the same problem. It may be noted that the ba problem was the first one given to the WR group, while it was the sixth or seventh pair for the PR group, who were then more experienced in the apparatus.

Insert Table 14 about here

The comparison of total errors to criterion for first vs. second paw for operated animals that reached criterion is shown in Figure 5. Learning occurred in the case of problem ba for the PR group, and the pairs of error values fall close to the $X = Y$ line for this group.

Insert Figure 5 about here

The results shown in Figures 3, 4, and 5 are summarized in Table 15. This table gives r, R_1, and R_2 values as described in connection with Table 8, for total trials, total correct, and total errors to criterion for operated animals that learned the problems. For the ba problem, there is a high correlation for the PR group of four cases. An equally high negative correlation appears for three ba cases in the WR group. The R_2 values correspond to the correlations in this instance.

Insert Table 15 about here

Figures 6 and 7 are from Tables 5 and 7 for split brain cats. These show that for the WR group the second paw learning is accomplished with fewer trials than the first paw learning (on problems 1-6) regardless of whether the left or right paw was first. For the PR group, first and second paw learning trials (on problems 11-14) were approximately equal. The second paw learning usually required a few more trials than the first paw learning regardless of whether the left or right paw learned first.

Insert Figures 6 and 7 about here

In general, then, we find the same result for the conventional measures as for the learning parameters. The second paw results cannot generally be regarded as replications of first paw results. Great variability in response was encountered within and between animals. In terms of conventional measures the results on normal animals showed in general marked savings on second paw learning in problems where the criterion was reached, indicating a high degree of transfer as expected. The one normal animal in the PR group which went through seven pairs of problems showed more variation in responses as later problems were attempted. The variability found in the split brain animals has been noted by other investigators. Variability of response was discussed by Voneida and Robinson (1970) and Robinson and Voneida (1970) in their investigations of performance on visual problems under monocular vs. binocular input in normal and split brain cats. Glickstein and Sperry (1960) working with rhesus monkeys noted that position habits did develop and "non-specific effects" confounded the savings scores. These investigators used as a comparison measure the first 40 trials of the second paw on a tactile problem. This is similar to the Rho_0 measure in the present study (initial probability of a correct response). Myers (1956), using cats, discusses deterrent effects of position habits on learning visual problems and on measuring unrewarded transfer tests. The most stable results in the present study were found using problems all cats could learn, giving a desired reward, and suppressing repeated incorrect responses.

Meikle, Sechzer, and Stellar (1962) studied respiratory and flexion responses to shock paired with skin stimulation. Respiratory responses were rapidly relearned, but limb flexion failed to demonstrate any transfer in the corpus callosum sectioned cats and required complete retraining. They suggest that the degree of hemispheric interaction depends largely upon the type of response learned, with highly corticalized responses (such as limb flexion) appearing to require an intact corpus callosum during training.

Russell, Plotkin, and Kleinman (1970) studied learning in the functional split brain rat, and report results in which correlation between first and second brain learning is essentially zero, when the same problem results are examined for the individual animals. They used learning to criterion of consecutive integrated escape responses from shock. Split brain animals showed marked emotional responses. "Classically conditioned CERs (conditioned emotion responses) failed to lateralize, but they did not facilitate the acquisition of escape behavior with the new hemisphere." When these investigators compared the mean number of trials required to reach each of five different criteria of learning (CL) an almost perfect correlation was found. This held only, however, for the means of groups trained to different criteria. On comparing individual results the correlations were near zero. These findings do not agree with the view that second-brain learning replicates first-brain learning.

Some results reported by Best (1965) in his thesis are of interest. He reported results from a reanalysis of data supplied by Meikle (1960, 1964) and by Meikle and Sechzer (1960) on visual problems. There were nine animals with transection of the corpus callosum and optic chiasma, four

of whom had deep split brain sections. A brightness problem and a figure problem were studied. A high correlation was found between first and second eye learning with savings scores ranging from -10% to +20%. He fitted curves to the data and got values of Alpha and Gamma 2 - Beta (which Best termed S) with high correlations.

Finally, the recent studies of Robinson and Voneida (1973) and of Webster (1972) have demonstrated that a considerable degree of functional asymmetry exists between the two brain halves. Results obtained in the present study are in general agreement with the latter, in that they fail to support the idea that the two hemispheres are identical. It must be concluded, therefore, that under conditions of the present experiment at least, the two brain halves, surgically separated by forebrain commissurotomy, may function as quite disimilar units.

Possibly under some conditions second brain learning replicates first brain learning, and under other conditions there is no such replication. If limited conditions under which second brain learning replicates first brain learning do exist, then an investigation of learning curve theories through replication by split brain experiments would be possible.

In the present investigation the major parameters were Rho_0, the initial probability of a correct response, and Alpha, the influence of reward of a correct response in increasing the strength of the correct response. Both parameters are based on a maximum likelihood estimate using the entire learning record. The other parameters were usually negligible.

References

Audley, R. J., and A. R. Jonckheere. 1956. The statistical analysis of the learning process. II. Stochastic processes ıd learning behavior. Brit. J. Statist. Psychol. 9: 87-94.

Best, P. J. 1965. "An Experimental Investigation of a Mathematical Learning Model." Unpublished doctoral dissertation, Princeton University. (Also Office of Naval Research Technical Report and ETS Research Bulletin 66-15. Educational Testing Service, Princeton, N. J., 1966.)

Glickstein, M., and R. W. Sperry. 1960. Intermanual somesthetic transfer in "split-brain" rhesus monkeys. J. Comp. Physiol. Psychol. 53: 322-327.

Gulliksen, H. 1934. A rational equation of the learning curve based on Thorndike's Law of Effect. J. Gen. Psychol. 11: 395-434.

Gulliksen, H. 1953. A generalization of Thurstone's learning function. Psychometrika 18: 297-307.

Meikle, T. H., Jr. 1960. Role of the corpus callosum in transfer of visual discriminations in the cat. Science 132: 1496.

Meikle, T. H., Jr. 1964. Failure of interocular transfer of brightness discrimination. Nature 202: 1243-1244.

Meikle, T. H., Jr., and J. A. Sechzer. 1960. Interocular transfer of brightness discrimination in "split brain" cats. Science 132: 734-735.

Meikle, T. H., Jr., J. A. Sechzer, and E. Stellar. 1962. Interhemispheric transfer of tactile conditioned responses in corpus callosum-sectioned cats. J. Neurophysiol. 25: 530-543.

Myers, R. E. 1956. Function of the corpus callosum in interocular transfer. Brain 79: 358-363.

Ramsay, J. O. 1970. A family of gradient methods for optimization. Computer J. 13: 413-417.

Robinson, J. S., and T. J. Voneida. 1970. Quantitative differences in performance on abstract discriminations using one or both hemispheres. Exptl. Neurol. 26: 72-83.

Robinson, J. S., and T. J. Voneida. 1973. Hemisphere differences in cognitive capacity in the split-brain cat. Exptl. Neurol. 38: 123-134.

Russell, I. S., H. C. Plotkin, and D. Kleinman. 1970. Task difficulty and lateralization of learning in the functional split-brain rat. Physiol. Behav. 5: 469-478.

Sperry, R. W. 1961. Cerebral organization and behavior. Science 133: 1749-1757.

Stamm, J. S., and R. W. Sperry. 1957. Function of corpus callosum in contralateral transfer of somesthetic discriminations in cats. J. Comp. Physiol. Psychol. 50: 138-143.

Voneida, T. J., and J. S. Robinson. 1970. Effect of brain bisection on capacity for cross comparison of patterned visual input. Exptl. Neurol. 26: 60-71.

Webster, W. G. 1972. Functional asymmetry between the cerebral hemispheres of the cat. Neuropsychologia 10: 75-87.

Footnote

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Table 1

Sequence of Problems Used for WR Group

Code	Order	Stimuli	Material and Shape
ba	#1, #2	Brush vs. flat	Bristle brush vs. flat wood block
dc	#3, #4	Round vs. wedge	Smooth metal half sphere vs. metal wedge
hg	#5, #6	Horizontal vs. vertical	Metal ridges with spaces between

Note.--Code letter on left signifies positive stimulus. Surgery done before ba problem or after it, sectioned corpus callosum (cc), and anterior commissure (ac).

Table 2

Sequence of Problems Used for PR Group

Code	Order	Stimuli	Material and Shape
ba or ab	#1, #3	Brush vs. flat b a	Bristle brush vs. flat wood block Positive stimulus reversed from #1 to #3
dc or cd	#2, #6	Round vs. wedge d c	Smooth metal half sphere vs. metal wedge
fe or ef	#4, #5	Doormat-f, sponge-e	Tined rubber doormat vs. firm rubber sponge
hg or gh	#7, #8	Horizontal-h, vertical-g	Flat metal bars with spaces between
df or fd	#9, #10	Round vs. doormat d f	Smooth metal half sphere vs. tined rubber doormat
ba or ab	#11, #12	Brush vs. flat b a	Bristle brush vs. flat wood block
ab or ba	#13, #14	Flat vs. brush a b	Flat wood block vs. bristle brush Reversal of positive stimulus from #11, 12

Note.--Code letter on left signifies positive stimulus. Surgery done as indicated in later tables. The pairs of problems were done with the same positive stimulus for both paws, except problems #1 and #3.

Table 3

	Increase in Strength of		
	Correct Response	Incorrect Response	Both Responses
With Occurrence of			
Correct Response	α	$\gamma_1 - \alpha$	γ_1
Incorrect Response	β	$\gamma_2 - \beta$	γ_2

Table 4

Values for Learning Parameters--WR Group, Normals

Code	Trials	Rho_0	Alpha	Beta	Gamma 1-A	Gamma 2-B	%OK in 3SD
Syba3-1	903	.3996	.005127	.0	.0	.0	90+
Syba1-2	658	.5728	.004535	.0	.0	.0	90+
Sydc2-3	1697	.6215	.001139	.0	.0	.0	100
Sydc4-4	1502	.4117	.002849	.0	.0	.0	100
Amba1-1	3259	.4669	.0005042	.0	.0	.0	90+
Amba3-2	1817	.5350	.0	.008516	.000176	.0	90+
Amdc2-3	858	.4609	.003034	.000623	.0	.0	90+
Amdc4-4	1803	[a]					
Amhg1-5	1416	.5487	.001141	.0	.0	.0	90+
Amhg3-6	200	[a]					

Note.--Code: First two letters = cat; second two letters = problem; first digit, 1 or 2 = left paw trained, 3 or 4, right paw. Second digits, sequence number of problem.

[a] = convergence was not reached, program was unsuccessful in identifying values of the parameters where the likelihood function was at a maximum.

Table 5

Values for Learning Parameters--WR Group, Operated, cc-ac or cc[a]

Code	Trials	Rho_0	Alpha	Beta	Gamma 1-A	Gamma 2-B	%OK in 3 SD
Chdc4-3	2680	.4242	.001089	.0	.0	.0	90+
Chdc2-4	1375	.4185	.003493	.0	.0	.0	90+
Chhg3-5	1307	.5015	.002483	.0	.0	.0	90+
Chhg1-6	550	.5298	.01548	.0	.0	.0	90+
Padc2-3	914	.4865	.004704	.0	.0	.0	90+
Padc4-4	485	.5363	.004193	.0	.0	.0	90+
Pahg3-5	752	.5154	.003765	.003325	.0	.0	90+
Pahg1-6	1200	.4178	.002689	.0	.0	.0	90+
Arba1-1	1225	.3126	.007345	.0	.0	.0	90+
Arba3-2	1333	.4721	.002433	.0	.0	.0	90+
Ardc2-3	884	.4484	.004892	.0	.0	.0	90+
Ardc4-4	547	.4621	.01180	.0	.0	.0	90+
Toba1-1	1598	.3556	.002049	.0	.0	.0	90+
Toba3-2	614	.5561	.009095	.0	.0	.0	90+
Tohg1-5	2619	.5064	.001414	.0	.0	.0	90+
Tohg3-6	1901	.5697	.001266	.0	.0	.0	90+
Cadc2-3	1567	.5626	.000991	.0	.0	.0	90+
Cadc4-4	1478	.5568	.001387	.0	.0	.0	90+
Cahg3-5	2117	.4593	.001237	.0	.0	.0	90+
Cahg1-6	629	.5995	.009687	.0	.0	.0	90+

Table 5 - continued

Code	Trials	Rho_0	Alpha	Beta	Gamma 1-A	Gamma 2-B	%OK in 3 SD
Hoba1-1	912	.3991	.002887	.0	.0	.0	90+
Hoba3-2	902	.3942	.005247	.0	.0	.0	90+
Hohg1-4	1861	.4971	.001761	.0	.0	.0	90+
Hohg3-5	551	.2688	.01834	.0	.0	.0	90+
Hocd1-6	2563	.6605	.000305	.0	.0	.0	90+
Hocd3-7	800	.4091	.005606	.0	.0	.0	90+
Bahg3-3	2352	.5910	.001133	.0	.0	.0	90+
Bahg1-4	1119	.6419	.001995	.0	.0	.0	90+

Note.--Code is same as for Table 4.

[a]Cats Ch, To, and Ca had the corpus callosum sectioned; cats Pa, Ar, Ho, and Ba had the anterior commissure also sectioned.

Table 6

Values for Learning Parameters--PR Group, Normals

Code	Trials	Rho_0	Alpha	Beta	Gamma 1-A	Gamma 2-B	%OK in 3 SD
Ruba4-1	292	.5765	.033020	.402000	.0	.0	100
Ruab1-3	752	.4951	.027760	.025470	.0	.0	90
Ruba4-11	1451	.3786	.006964	.0	.002041	.0	91
Ruba2-12	1583	.4385	.000809	.0	.0	.0	77[a]
Ruab3-13	1528	.2569	.002855	.0	.0	.0	79[a]
Ruab1-14	1857	.7084	.0	.003250	.0	.0	75[a]
Evab1-1	1266	.5616	.002988	.006368	.0	.0	99
Evba4-3	757	.3732	.0	.095360	.000795	.0	96
Evef2-4	662	.2431	.063420	.0	.0	.0	100
Evef4-5	606	.6960	.869100	.0	.005000	.0	100
Ldab3-1	2359	.4431	.001349	.0	.0	.0	90
Ldba2-3	995	.6339	.002388	.0	.0	.0	95
Clab3-1	2027	.3774	.001298	.0	.0	.0	84
Clef4-4	665	.5986	.009052	.041490	.0	.0	100
Clef2-5	482	.2966	.0	.305500	.0	.0	95
Fiba2-1	1242	.2687	.006835	.0	.0	.0	100
Fiab3-3	493	.6648	.061250	.0	.0	.0	100

Note.--Code is same as for Table 4.

[a]Criterion of learning not reached.

Table 7

Values for Learning Parameters--PR Group, Operated, cc-ac

Code	Trials	Rho_0	Alpha	Beta	Gamma 1-A	Gamma 2-B	%OK in 3 SD
Evba2-13	1428	.1612	.004983	.0	.0	.0	86
Evba4-14	1699	.2372	.002944	.0	.0	.0	97
Clab3-11	1562	.4414	.0	.001326	.0	.0	71[a]
Clab1-12	1613	.3774	.0	.000662	.0	.0	71[a]
Clba4-13	1365	.4624	.003014	.0	.0	.0	90
Clba2-14	1518	.4266	.001132	.008853	.0	.000943	93
Ldab3-11	1760	.2541	.0	.01098	.009572	.0	68[a]
Ldab1-12	1696	.0	.000011	.01496	.00856	.00996	57[a]
Ldba4-13	1446	.2764	.003887	.0	.0	.0	87
Ldba2-14	1616	.5996	.000017	.00024	.0	.0	81
Fiba2-11	1186	.4086	.003131	.0	.0	.0	94
Fiba4-12	1231	.3188	.007168	.0	.0	.0	96
Fiab1-13	1294	.05708	.0052	.0	.0	.0	78[a]
Fiab3-14	1732	.05371	.02843	.0	.01501	.0	75[a]

Note.--Code is same as for Table 4.

[a]Criterion of learning not reached.

Table 8

Relationships between Left and Right Paw

Learning Measures in Split Brain Cats.

Parameter Values in Learning Tactile Problems.

Parameter	R_2	R_1	r	# Cases
Rho_0	0.132	0.215	0.217	4 pairs PR (all ba)
Rho_0	0.081	0.083	0.083	14 pairs WR
Alpha	-0.150	-0.104	-0.195	4 pairs PR (all ba)
Alpha	0.045	0.045	0.076	14 pairs WR
Beta	0.0	0.0/0.0	0.0/0.0	4 pairs PR (all ba)
Beta	0.0/0.0	0.0/0.0	0.0/0.0	14 pairs WR

Table 9

Total # Trials to Three Highest Days--WR Group

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	2nd paw	
Syba3,1-1,2	753	90	506	90	+33	N	N	LP[c]
Amba1,3-1,2	3110	90	1668	90	+46	N	N	LP
Paba3,1-1,2	350	96	156	99	+55	N	N	
Baba1,3-1,2	3762	97	1042	96	+72	N	Op[b]	
Chba3,1-1,2	547	95	423	96	+29	N	Op	
Arba1,3-1,2	1076	90	1134	90	-5	Op	Op	LP
Toba1,3-1,2	1398	90	465	90	+67	Op	Op	LP
Caba3,1-1,2	1757	90	631	90	+64	Op	Op	
Hoba1,3-1,2	709	90	750	90	-6	Op	Op	LP
Sydc2,4-3,4	2999	90	1349	98	+55	N	N	LP
Amdc2,4-3,4	709	92	1654	96	-57	N	N	LP
Padc2,4-3,4	750	90	350	90	+53	Op	Op	
Badc3,1-3,4	2889	57	[a]			Op	Op	
Chdc4,2-3,4	2581	95	1226	98	+52	Op	Op	LP
Ardc2,4-3,4	736	95	398	96	+46	Op	Op	LP
Todc2,4-3,4	1540	59	[a]			Op	Op	
Cadc2,4-3,4	1418	91	1329	95	+6	Op	Op	LP
Hocd1,3-3,4	2414	92	651	92	+73	Op	Op	LP

Table 9 - continued

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	2nd paw	
Amhg1,3-5,6	1267	95	51	97	+96	N	N	LP
Pahg3,1-5,6	603	90	1051	92	-74	Op	Op	LP
Bahg3,1-5,6	2593	95	970	97	+63	Op	Op	LP
Chhg3,1-5,6	1158	90	401	97	+65	Op	Op	LP
Arhg1,3-5,6	000	90	750	94	-0	Op	Op	
Tohg1,3-5,6	2419	93	1752	94	+28	Op	Op	LP
Cahg3,1-5,6	1918	93	480	99	+75	Op	Op	LP
Hohg1,3-5,6	2662	95	401	92	+85	Op	Op	LP

Note.--Code: 1st two letters = cat; 2nd two letters = problem
1st two digits = sequence of paw used; 1,2 = left; 3,4 = right
2nd set of digits = sequence # of problem

[a]Criterion of learning not reached.

[b]Op = same as in Table 5 footnote.

[c]LP = learning parameters given in earlier tables 4 and 5.

Table 10

Total # Trials to Three Highest Days--PR Group

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw	
Rudc3,1-2,6	508	90	29	94	+94	N	N	
Fidc1,3-2,6	892	90	40	83	+96	N	Op[b]	
Evcd2,4-2,6	3050	90	404	90	+87	N	N	
Ldcd4,2-2,6	1239	88	210	89	+83	N	Op	
Clcd4,2-2,6	1171	85	197	90	+83	N	N	
Fifel,3-4,5	138	100	40	100	+71	N	N	
Evef2,4-4,5	174	100	0	100	+100	N	N	LP[c]
Ldef4,2-4,5	13	100	0	96	+100	N	N	
Clef4,2-4,5	154	100	260	95	-69	N	N	LP
Ruhg3,1-7,8	46	73[a]	1301	65[a]	-2728	N	N	
Fighl,3-7,8	36	83	281	80	-681	Op	Op	
Evhg2,4-7,8	1350	65[a]	1982	76[a]	-47	Op	Op	
Ldhg4,2-7,8	852	79[a]	2760	65[a]	-224	Op	Op	
Clhg4,2-7,8	284	65[a]	2480	64[a]	-773	Op	Op	
Rudf4,2-9,10	718	73[a]	673	78[a]	+6	N	N	
Fidf2,4-9,10	1193	83	441	80	+63	Op	Op	
Evfdl,3-9,10	2253	48[a]	809	63[a]	+64	Op	Op	
Lddf4,2-9,10	423	80	844	61[a]	-100	Op	Op	
Clfd3,1-9,10	1063	45[a]	[a]					
Ruab3,1-13,14	1414	79[a]	272	75[a]	+81	N	N	LP
Fiabl,3-13,14	1179	78[a]	1287	75[a]	-9	Op	Op	LP
Evabl,3-11,12	1624	66[a]	800	56[a]	+51	Op	Op	
Ldab3,1-11,12	1228	68[a]	1548	57[a]	-26	Op	Op	LP
Clab3,1-11,12	1332	71[a]	1434	71[a]	-8	Op	Op	LP

Table 10 - continued

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	2nd paw	
Ruba4,2-11,12	941	92	1137	77[a]	-21	N	N	LP
Fiba2,4-11,12	961	94	976	96	-2	Op	Op	LP
Eyba2,4-13,14	1178	86	1542	97	-31	Op	Op	LP
Ldba4,2-13,14	1308	87	1377	81	-5	Op	Op	LP
Clba4,2-13,14	1132	90	1357	93	-20	Op	Op	LP

Note.--Code: 1st two letters = cat; 2nd two letters = problem
1st two digits = sequence of paw used; 1,2 = left; 3,4 = right
2nd set of digits = sequence of problem

[a]Criterion of learning not reached

[b]Op = cc-ac.

[c]LP = learning parameters given in earlier tables 6 and 7.

Table 11

Total # Correct Responses to Three Highest Days--WR Group

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw
Syba3,1-1,2	498	90	365	90	+27	N	N
Amba1,3-1,2	1892	90	1293	90	+32	N	N
Paba3,1-1,2	253	96	129	99	+49	N	N
Chba3,1-1,2	367	95	214	96	+42	N	Op[b]
Arba1,3-1,2	783	90	769	90	+2	Op	Op
Toba3,1-1,2	817	90	363	90	+56	Op	Op
Caba3,1-1,2	1105	90	464	90	+58	Op	Op
Hoba1,3-1,2	378	90	497	90	-32	Op	Op
Sydc2,4-3,4	2020	90	365	98	+27	N	N
Amdc2,4-3,4	454	92	1280	96	-182	N	N
Padc2,4-3,4	536	90	216	90	+60	Op	Op
Badc3,1-3,4	[a]		[a]			Op	Op
Chdc4,2-3,4	1674	95	855	98	+49	Op	Op
Ardc2,4-3,4	507	95	289	96	+43	Op	Op
Todc2,4-3,4	[a]		[a]			Op	Op
Cadc2,4-3,4	955	91	922	95	+4	Op	Op
Hocd1,3-3,4	1732	92	432	92	+75	Op	Op

Table 11 - continued

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	2nd paw
Amhg1,3-5,6	826	95	41	97	+95	N	N
Pahg3,1-5,6	439	90	667	92	-52	Op	Op
Bahg3,1-5,6	1995	95	736	97	+63	Op	Op
Chhg3,1-5,6	820	90	322	97	+61	Op	Op
Arhg1,3-5,6	137	90	515	94	-276	Op	Op
Tohg1,3-5,6	1779	93	1276	94	+28	Op	Op
Cahg3,1-5,6	1239	93	386	99	+69	Op	Op
Hohg1,3-5,6	1949	95	277	92	+86	Op	Op

Note.--Code same as for Tables 9 and 10.

[a]Criterion of learning not reached.

[b]Op = same as in Table 5 footnote.

Table 12

Total # Correct Responses to Three Highest Days--PR Group

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw
Rudc3,1-2,6	392	90	21	94	+95	N	N
Fidc1,3-2,6	709	90	33	83	+95	N	Op
Evcd2,4-2,6	1770	90	330	90	+81	N	N
Ldcd4,2-2,6	806	88	159	89	+80	N	Op
Clcd4,2-2,6	705	85	150	90	+79	N	N
Rufe3,1-4,5	[a]						
Fife1,3,4,5	112	100	29	100	+74	N	N
Evef2,4-4,5	120	100	0	100	+100	N	N
Ldef4,2-4,5	12	100	0	96	+100	N	N
Clef4,2-4,5	120	100	226	95	-88	N	N
Ruhg3,1-7,8	26	73[a]	598	65[a]	-2200	N	N
Fighl,3-7,8	24	83	194	80	-708	Op	Op
Evhg2,4-7,8	687	65[a]	881	76[a]	-28	Op	Op
Ldhg4,2-7,8	550	79[a]	1386	65[a]	-152	Op	Op
Clhg4,2-7,8	156	65[a]	1306	64[a]	-737	Op	Op

Table 12 - continued

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	2nd paw
Rudf4,2-9,10	348	73[a]	390	78[a]	-12	N	N
Fidf2,4-9,10	700	83	250	80	+64	Op	Op
Evfd1,3-9,10	618	48[a]	318	63[a]	+49	Op	Op
Lddf4,2-9,10	270	80	420	61[a]	-56	Op	Op
Clfd3,1-9,10	330	45[a]	318	63[a]	+49	Op	Op
Ruab3,1-13,14	812	79[a]	176	75[a]	+78	N	N
Fiab1,3-13,14	477	78[a]	701	75[a]	-47	Op	Op
Evab1,3-11,12	658	66[a]	286	56[a]	+57	Op	Op
Ldab3,1-11,12	598	68[a]	661	57[a]	-11	Op	Op
Clab3,1-11,12	759	71[a]	702	71[a]	+8	Op	Op
Ruba4,2-11,12	589	92	586	77[a]	+1	N	N
Fiba2,4-11,12	601	94	695	96	-16	Op	Op
Evba2,4-13,14	656	86	870	97	-33	Op	Op
Ldba4,2-13,14	830	87	847	81	-2	Op	Op
Clba4,2-13,14	794	90	1007	93	-27	Op	Op

Note.--Code same as for Tables 9 and 10.

[a]Criterion of learning not reached.

Table 13

Total # Errors to Three Highest Days--WR Group

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw
Syba3,1-1,2	255	90	141	90	+45	N	N
Amba1,3-1,2	1218	90	375	90	+69	N	N
Paba3,1-1,2	97	96	27	99	+72	N	N
Chba3,1-1,2	180	95	209	96	-16	N	Op[b]
Arba1,3-1,2	293	90	365	90	-75	Op	Op
Toba1,3-1,2	581	90	102	90	+82	Op	Op
Caba3,1-1,2	652	90	167	90	+74	Op	Op
Hoba1,3-1,2	331	90	253	90	+24	Op	Op
Sydc2,4-3,4	979	90	435	98	+55	N	N
Amdc2,4-3,4	255	92	374	96	-47	N	N
Padc2,4-3,4	214	90	134	90	+37	Op	Op
Badc3,1-3,4	[a]		[a]			Op	Op
Chdc4,2-3,4	907	95	371	98	+59	Op	Op
Ardc2,4-3,4	229	95	109	96	+52	Op	Op
Todc2,4-3,4	[a]		[a]			Op	Op
Cadc2,4-3,4	463	91	407	95	+12	Op	Op
Hocd1,3-3,4	682	92	219	92	+68	Op	Op

Table 13 - continued

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw
Amhg1,3-5,6	441	95	10	97	+98	N	N
Pahg3,1-5,6	164	90	384	92	-134	Op	Op
Bahg3,1-5,6	598	95	234	97	+61	Op	Op
Chhg3,1-5,6	338	90	79	97	+77	Op	Op
Arhg1,3-5,6		90	235	94	-1707	Op	Op
Tohg1,3-5,6	640	93	476	94	+26	Op	Op
Cahg3,1-5,6	679	93	94	99	+86	Op	Op
Hohg1,3-5,6	713	95	124	92	+80	Op	Op

Note.--Code same as for Tables 9 and 10.

[a]Criterion of learning not reached.

[b]Op = same as in Table 5 footnote.

Table 14

Total # Errors to Three Highest Days--PR Group

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw
Rudc3,1-2,6	116	90	8	94	+93	N	N
Fidc1,3-2,6	183	90	7	83	+96	N	Op
Evcd2,4-2,6	1280	90	74	90	+94	N	N
Ldcd4,2-2,6	433	88	51	89	+88	N	Op
Clcd4,2-2,6	466	85	47	90	+90	N	N
Fife1,3-4,5	26	100	11	100	+58	N	N
Evef2,4-4,5	54	100	0	100	+100	N	N
Ldef4,2-4,5	1	100	0	96	+100	N	N
Clef4,2-4,5	34	100	34	95	0	N	N
Rugh3,1-7,8	20	73[a]	703	65[a]	-3415	N	N
Figh1,3-7,8	12	83	87	80	-625	Op	Op
Evhg2,4-7,8	663	65[a]	1101	76[a]	-66	Op	Op
Ldhg4,2-7,8	302	79[a]	1374	65[a]	-355	Op	Op
Clhg4,2-7,8	128	65[a]	1174	64[a]	-817	Op	Op
Rudf4,2-9,10	370	73[a]	283	78[a]	+24	N	N
Fidf2,4-9,10	493	83	191	80	+61	Op	Op
Evfd1,3-9,10	1635	48[a]	491	63[a]	+70	Op	Op
Lddf4,2-9,10	153	80	424	61[a]	-177	Op	Op
Clfd3,1-9,10	733	45	[a]			Op	Op

Table 14 - continued

Code	#1st paw	%OK in 3 SD	#2nd paw	%OK in 3 SD	Savings % of #1	N or Op 1st	N or Op 2nd paw
Ruab3,1-13,14	602	79[a]	96	75[a]	+84	N	N
Fiab1,3-13,14	702	78[a]	586	75[a]	+17	Op	Op
Evab1,3-11,12	966	66[a]	514	56[a]	+47	Op	Op
Ldab3,1-11,12	630	68[a]	887	57[a]	-41	Op	Op
Clab3,1-11,12	573	71[a]	732	71[a]	-28	Op	Op
Ruba4,2-11,12	352	92	551	77[a]	-57	N	N
Fiba2,4-11,12	360	94	284	96	+22	Op	Op
Evba2,4-13,14	522	86	672	97	-29	Op	Op
Ldba4,2-13,14	478	87	530	81	-11	Op	Op
Clba4,2-13,14	338	90	350	93	-4	Op	Op

Note.--Code same as for Tables 9 and 10.

[a]Criterion of learning not reached.

Table 15

Relationships between Left and Right Paw

Learning Measures in Split Brain Cats.

Total Trials, # Correct, and # Errors to Criterion.

Measure	R_2	R_1	r	# Cases
Total trials	0.352	0.680	0.771	4 pairs PR (all ba)
Total trials	-0.204	0.122	0.166	14 pairs WR
# OK trials	0.171	0.671	0.679	4 pairs PR (all ba)
# OK trials	-0.059	0.272	0.334	14 pairs WR
# errors	0.737	0.770	0.956	4 pairs PR (all ba)
# errors	-0.276	0.063	0.071	14 pairs WR
# errors	-0.957	-0.937	-0.950	3 pairs WR (all ba)

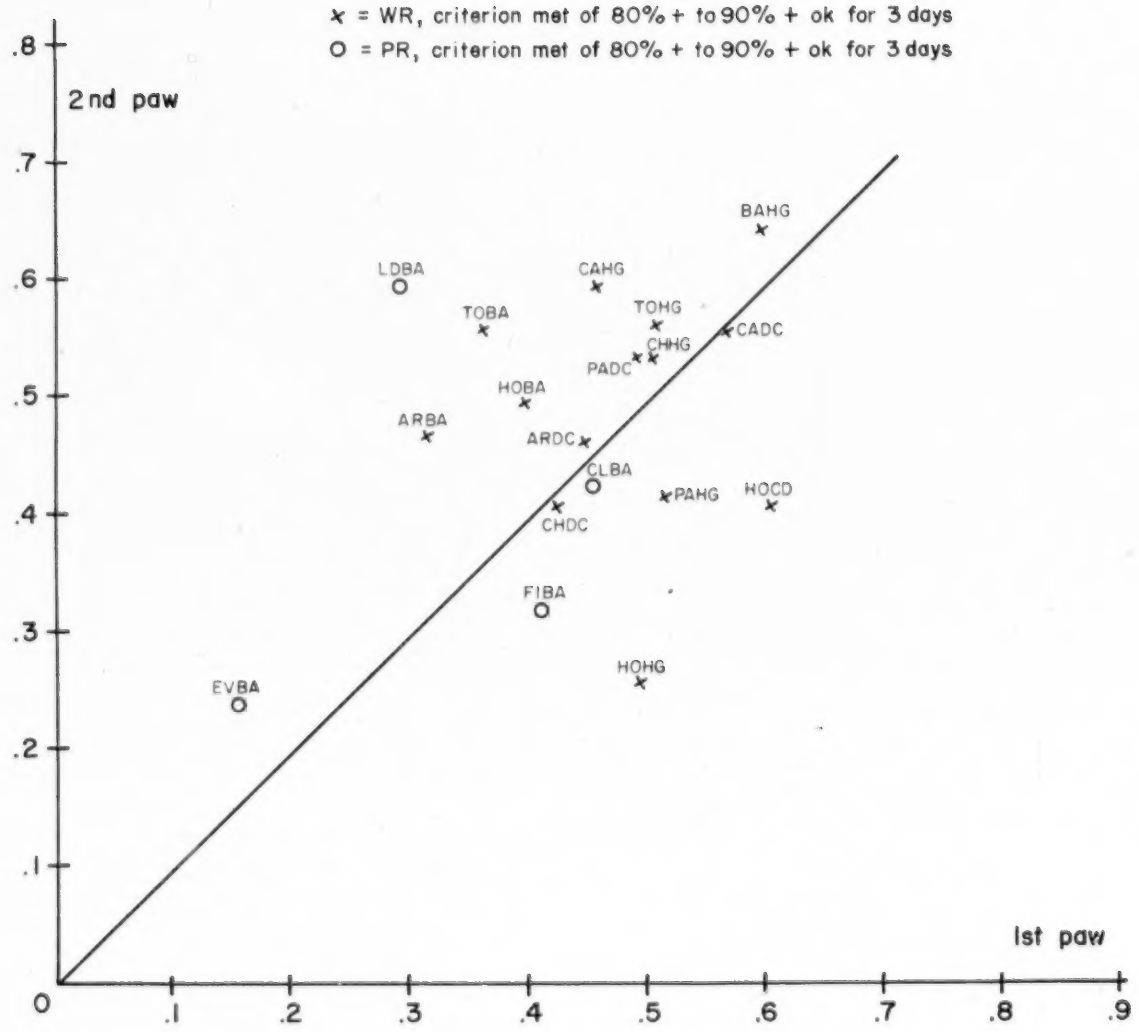

Fig. 1. Learning parameter, Rho_0 = initial probability of a correct response, split brain cats.

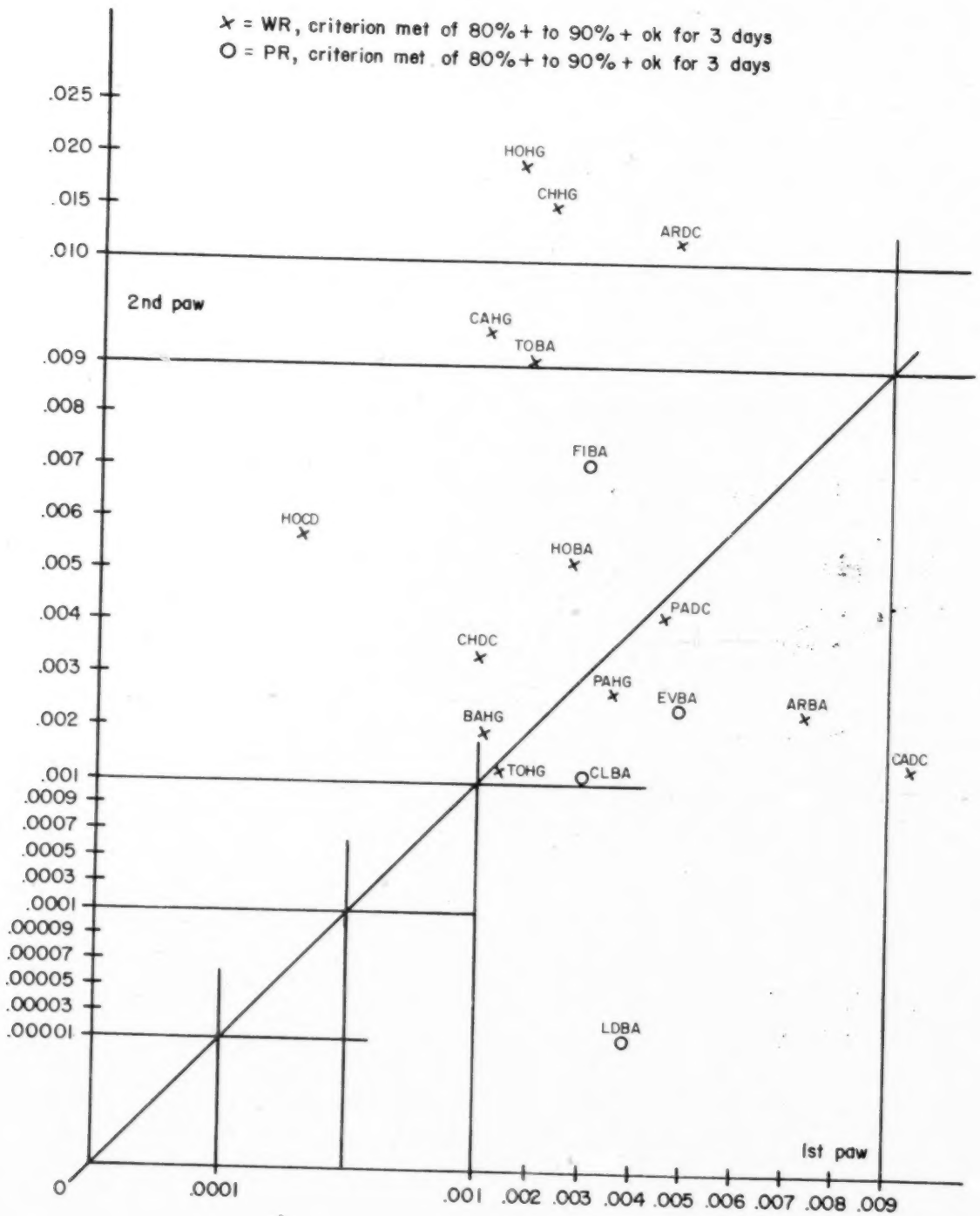

Fig. 2. Learning parameter, Alpha = effect of correct response on strength of correct response, split brain cats.

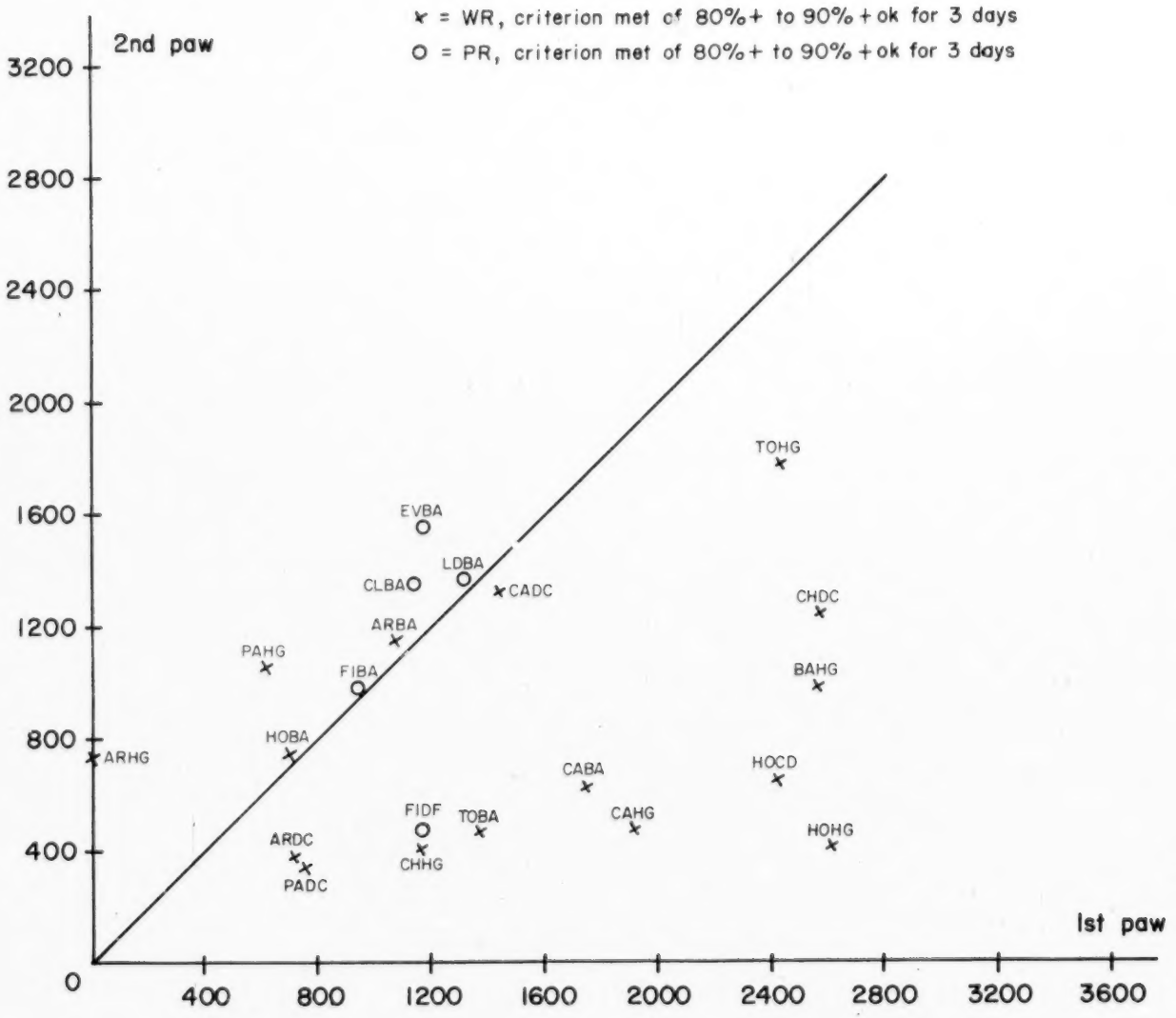

Fig. 3. Total trials to criterion, split brain cats.

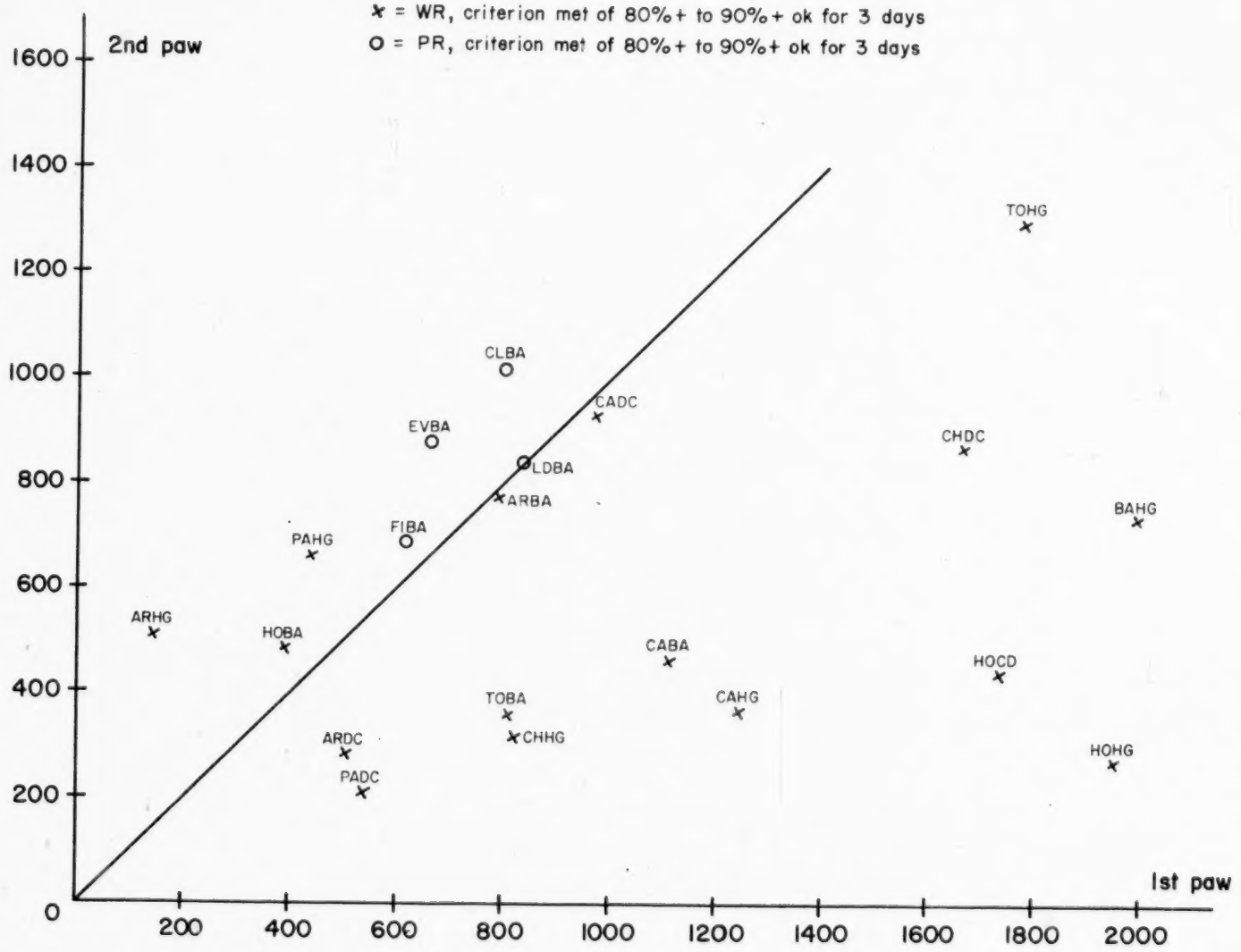

Fig. 4. Number of correct trials to criterion, split brain cats.

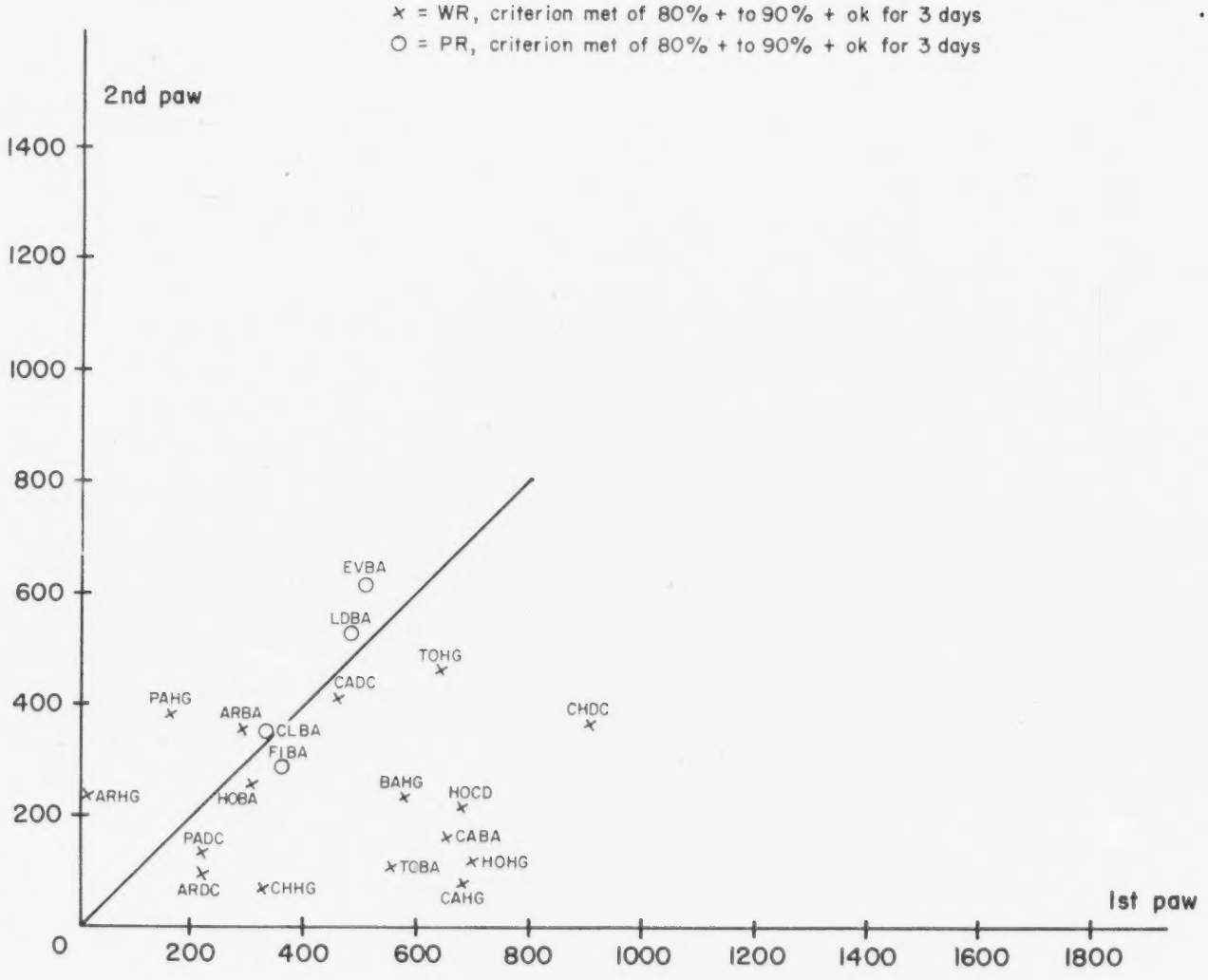

Fig. 5. Number of errors to criterion, split brain cats.

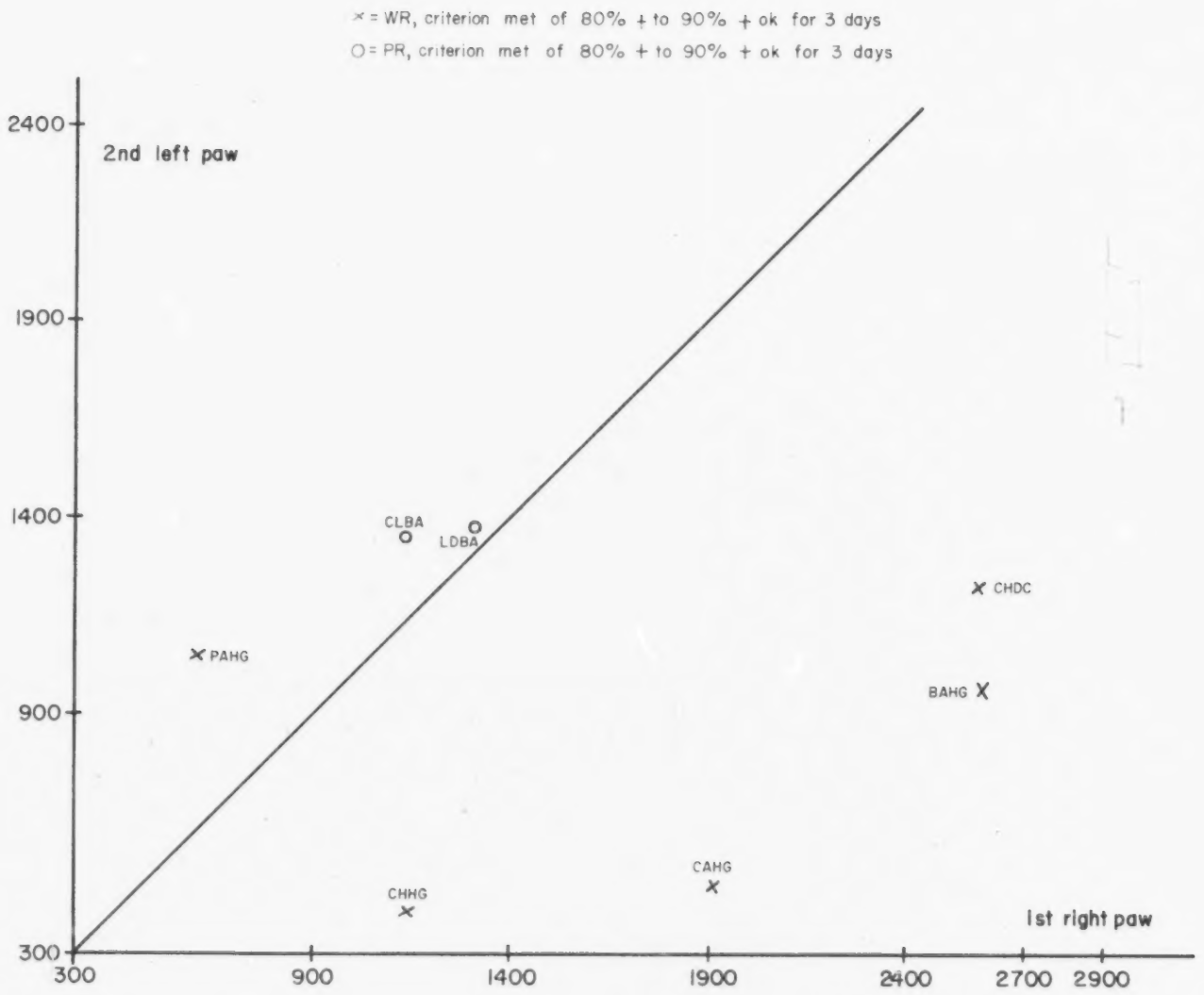

Fig. 6. Total trials, split brain cats, right paw first.

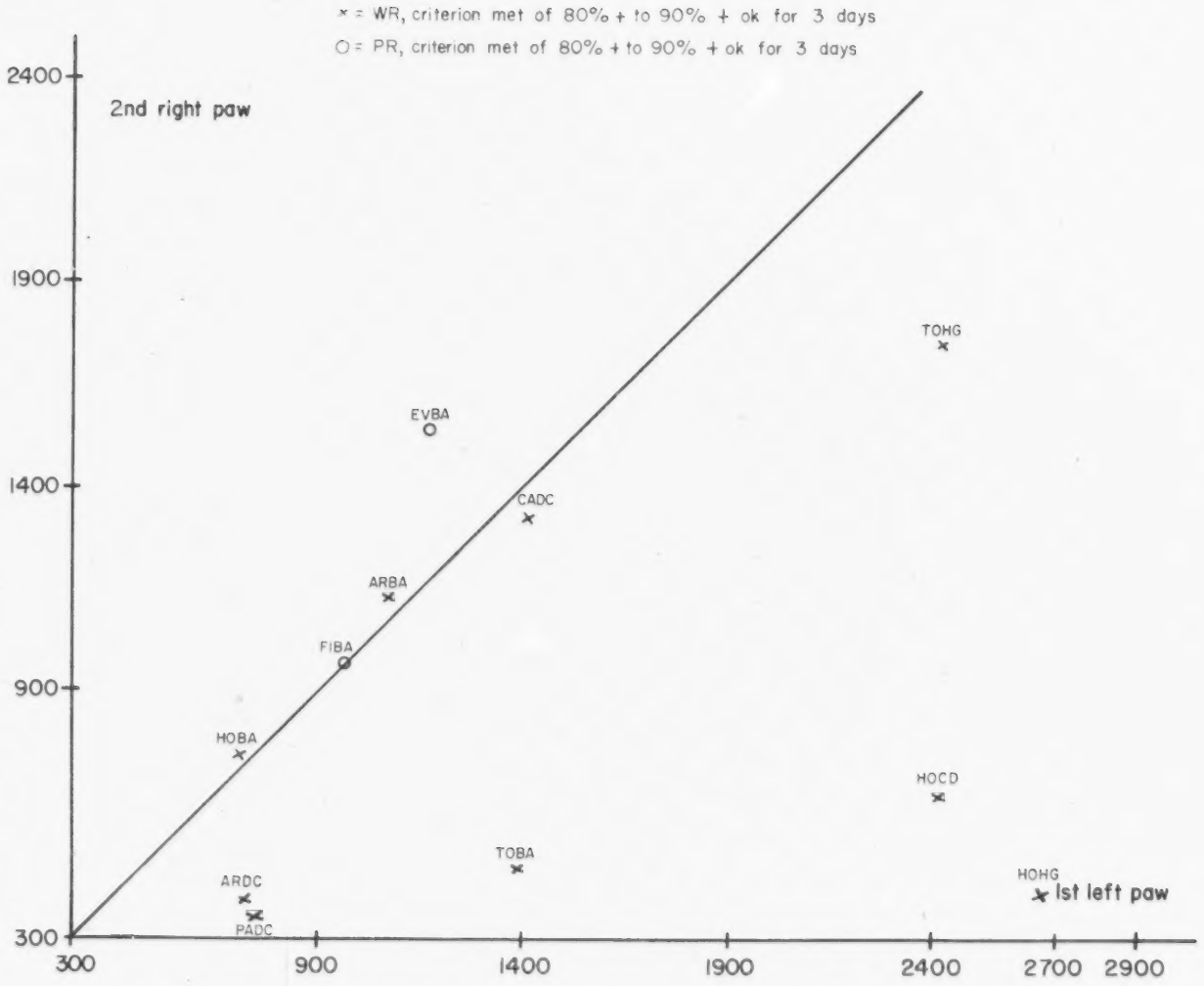

Fig. 7. Total trials, split brain cats, left paw first.

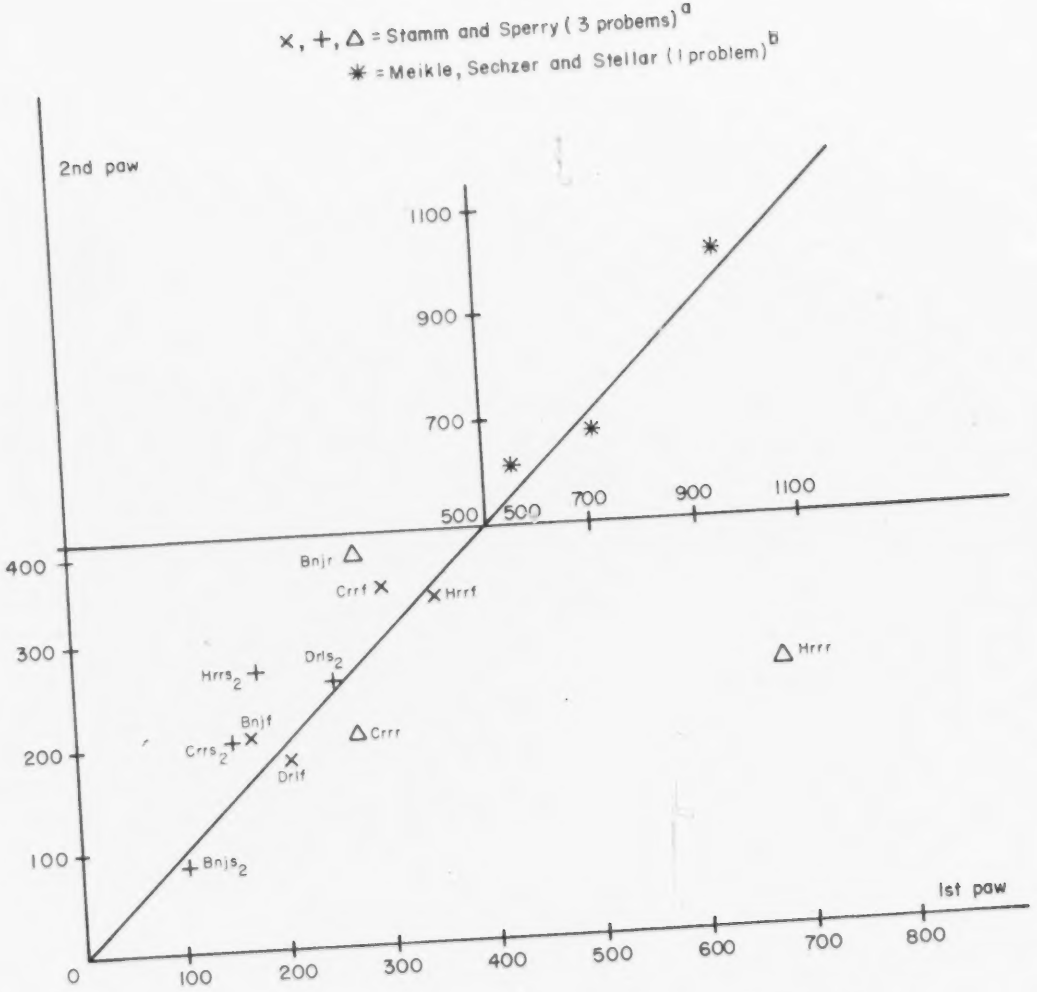

Fig. 8. Number of trials to criterion, split brain cats.

[a]Plotted from data in Stamm and Sperry (1957).

[b]Plotted from data in Meikle, Sechzer, and Stellar (1962).

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